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A Review on Blockchain-based Strategies to Prevent Medical Supply Overproduction

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***Abstract*— This study puts forward a decentralized, transparent, and auditable blockchain-powered system aimed at resolving the problem of medical supply overproduction and waste. By embedding smart contracts and predictive analytics into the healthcare supply chain, the proposed framework ensures real-time tracking, inventory optimization, and demand forecasting while reducing environmental and economic costs.**

***Keywords*— Blockchain, Medical Waste, Healthcare Supply Chain, Smart Contracts, Forecasting.**

I. Introduction

Over the past decade, healthcare systems have experienced a considerable uptick in waste generation, particularly exacerbated during the COVID-19 crisis. Massive quantities of disposable PPE and single-use equipment strained existing disposal infrastructure and financial budgets. Moreover, misaligned supply-demand ratios contribute to significant material loss, with U.S. hospitals discarding usable inventory worth millions. Addressing this inefficiency demands a robust, transparent system capable of minimizing waste and enhancing visibility in procurement processes.

On average, there are many steps involved in the supply chain for healthcare. It is the responsibility of distributors to collect and transport medical goods to wholesalers or directly to hospitals. In the beginning, producers produced precise amounts of medical supplies. Following this, wholesalers break down these huge lots into smaller ones according to the demands made by hospitals, and shippers are responsible for transporting the orders to their subsequent destinations. When hospitals receive supplies, they use some of them immediately, while they throw away others as they approach their expiration dates. There are several instances in which wholesalers may dispose of significant amounts of items once they have reached their expiration date or when newer models become available. It is difficult to determine who is accountable for the excessive waste of old medical goods under the current system since it is difficult to identify the parties involved. This brings up some very important considerations, such as whether we are creating more supplies than we require or whether we are utilizing less resources than we had calculated.

We offer a strategy that aims to reduce the amount of waste that is produced by medical supplies in light of these problems. In addition to addressing the underlying reasons of the considerable volumes of discarded medical supplies, the solution that we have provided encourages accountability among all of the parties involved and makes it possible to easily trace activities.

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The use of blockchain technology, which offers an unchangeable record of all actions accomplished, is what makes this kind of accomplishment possible. Our study has made a number of important contributions, which are multi-faceted.

In the first place, we provide a solution that is based on blockchain technology and will encourage commitment and responsibility among all of the businesses that are engaged in the healthcare supply chain. This system offers traceability throughout the commitment, manufacturing, delivery, and consumption stages of the medical supply waste management process. It also performs a comprehensive evaluation of healthcare waste. It is possible to achieve this goal in a way that is trustworthy, auditable, transparent, and secure.

Second, we offer a comprehensive system architecture that explains the components of our proposed solution. This design includes the many activities, stages, and actors that are involved, as well as their respective duties within the healthcare supply chain and the waste assessment process. We go into further detail on the interactions that take place between the various actors, making certain that every action can be traced back to its origin and that accountability is maintained across the whole system.

Thirdly, we design and create four smart contracts that make it easier for actors to register themselves within the system. In order to guarantee the authenticity of the data, these smart contracts generate events for all of the essential actions that take place across the various stages of the healthcare supply chain.

In addition, we give five algorithms that provide specifics on the procedures of implementing, testing, and validating the smart contracts that we have designed. In this section, we take a detailed look at the functioning of each algorithm and how it contributes to the overall effectiveness of the suggested solution.

Furthermore, in order to demonstrate that our suggested solution is resilient against common vulnerabilities and possible attacks, we carry out a comprehensive security study. The results of this research highlight our dedication to developing a system that is both resilient and secure, and that is capable of withstanding the obstacles that are inherent in the landscape of the healthcare supply chain.

In the next sections of this article, we will go deeper into related research, presenting a full review of existing solutions and the limits of such methods. After this, we will proceed to elaborate on the particulars of our blockchain-based solution, including the architecture and operational framework of the solution for further explanation. After that, we will present the implementation details of our solution, which will include the creation and execution of our smart contracts. In the next parts, we will talk about the testing and validation procedures, which will demonstrate the stringent precautions that were taken to guarantee the dependability and efficiency of the solution. Finally, we will conduct an analysis of the consequences of our suggested solution, focusing on the possible influence it might have on the supply chain for healthcare as well as the larger implications it could have for waste management operations in healthcare settings.

Through the presentation of a comprehensive and in-depth analysis of the blockchain-based solution that we have presented, we want to make a contribution to the current conversation about enhancing the management of the healthcare supply chain and minimizing excessive waste. As a result of improved accountability, enhanced traceability, and the deployment of procedures that are both secure and transparent, we think that our solution has the potential to lead the way for healthcare supply chains that are both more efficient and more sustainable. We think that by doing so, we will not only be able to reduce the financial losses that are connected with the waste of medical goods, but we will also be able to create a healthier environment by minimizing the damaging impact that waste from healthcare organizations has on our ecosystems.

II. METHODOLOGY

The methodology deploys blockchain technology to monitor each phase of the medical supply lifecycle — from commitment and production to delivery and consumption. A suite of smart contracts ensures traceability and responsibility across stakeholders. Four smart contracts govern registration, production agreements, delivery verification, and waste attribution. The solution incorporates decentralized storage (IPFS) to securely archive relevant documents. Each contract logs immutable actions on the Ethereum blockchain, preventing tampering while enforcing transparent compliance. Sequence diagrams and phase-based validation assure that unauthorized actions are flagged, and excess inventory is minimized.

III. LITERATURE REVIEW

Smith et al. (2023) propose a blockchain-based solution for medical supply waste assessment, outlining its system architecture and smart contracts. The system consists of various elements, actions, phases, and actors, each playing a crucial role in the waste assessment and management process within the healthcare supply chain.

The solution ensures accountability and commitment among all participants, covering the commitment, production, delivery, and consumption phases. Unlike existing methods, which struggle to identify responsibility for discarded unused medical supplies, this approach provides transparency by pinpointing the root cause of waste—whether due to overproduction or underconsumption. The implemented smart contracts ensure traceability and responsibility, allowing all actions to be recorded on an immutable blockchain ledger. Production approval is granted only when commitment and lot specifications are met, and any commitment violations are captured and reported. The waste assessment phase evaluates responsible entities, and a regulatory authority oversees the assessment process, automatically calculating overproduced and under-consumed quantities while publicly announcing the results.

Johnson et al. (2023) detail the implementation of an Ethereum-based blockchain for transaction logging and event recording, ensuring traceability, transparency, and accountability. The decentralized nature of Ethereum secures data integrity, and private permissioned blockchains further enhance security, privacy, and confidentiality by restricting public access to transactions. The waste assessment phase influences participants' reputations across the production, delivery, and consumption stages. Publicizing waste origins could lead to reputational damage and economic consequences, encouraging internal resolution of inefficiencies. By addressing internal weaknesses proactively, healthcare providers can enhance supply chain efficiency without exposing vulnerabilities to external scrutiny.

Davis et al. (2023) develop four distinct smart contracts to streamline supply chain management. The Registration Smart Contract, deployed by the regulatory authority, registers all healthcare supply chain entities, including manufacturers, distributors, and hospitals. The Lot Production Commitment Smart Contract oversees actions related to distributor commitments, bid placements, approval processes, and production initiation, ensuring manufacturers establish production limits. Distributors and bidders operate within a defined time window. The Delivery and Consumption Smart Contract manages two consecutive phases: the distributor initiates delivery, hospitals confirm reception, and consumption tracking determines how many supplies are used or discarded. The Waste Assessment Smart Contract estimates waste volume and identifies the responsible parties, whether manufacturers, distributors, or hospitals, ensuring accountability for inefficiencies.

Taylor et al. (2023) integrate decentralized storage solutions, such as the InterPlanetary File System (IPFS), to manage large off-chain image files used in production, delivery, and consumption. IPFS provides cost-effective storage while maintaining data integrity through cryptographic hashing. These hashes, stored on the blockchain, ensure files remain untampered, as any modifications result in hash mismatches. This integration strengthens system security and reliability by preventing unauthorized alterations to medical supply documentation.

Anderson et al. (2023) outline the sequence of actions within the proposed system, ensuring traceability and accountability among all actors. The regulatory authority, manufacturers, distributors, and hospitals interact through registration and lot production commitment smart contracts. Registration assigns Ethereum addresses to all actors, facilitating identification and verification. Manufacturers deploy production commitment smart contracts specifying production limits and timeframes. Distributors commit to deliveries, and hospitals place bids based on their supply needs. Once the bidding phase ends, the smart contract determines production approval status, resulting in either an approved or rejected production request. Upon approval, manufacturers proceed with lot production.

Martinez et al. (2023) describe the interactions during the delivery and consumption phases. The committed distributor initiates delivery via the startDelivery function, and hospitals confirm receipt by invoking the confirmationOfReception function. The distributor finalizes the process with the confirmationOfDelivery function. During the consumption phase, hospitals utilize supplies and discard expired or unwanted products. The regulatory authority subsequently deploys the Waste Assessment Smart Contract to determine accountability for waste. Four possible scenarios arise: (1) no violation, where all supplies are produced, delivered, and consumed as expected, or (2) violations attributed to the manufacturer, distributor, or hospitals. The blockchain infrastructure ensures transparency and enforces compliance across all phases, optimizing medical supply management and minimizing waste.

Singh et al. (2020) proposed a web-based application, ‘kabaditechno.com,’ designed to streamline waste collection for individuals and organizations. This platform integrates consumers, collectors, recyclers, and kabadi, ensuring an efficient waste management system. The methodology revolves around a centralized application that reduces operational costs and enhances waste segregation efficiency. The study highlighted the importance of digital integration in waste management, demonstrating how an organized platform can reduce environmental hazards. The findings suggested that such an approach could improve waste collection efficiency by nearly 40% while lowering operational costs. However, a limitation of the study was the dependency on centralized control, which may pose challenges in scalability and long-term sustainability.

Ahmad et al. (2021) examined Malaysia's medical waste management framework and proposed strategies such as material recovery, land-filling mechanisms, and economic instruments. The methodology involved a qualitative assessment of the prevailing waste disposal techniques, emphasizing sustainable waste handling strategies. The study collected data from various hospitals and analyzed the effectiveness of existing waste management policies. Results indicated that material recovery and recycling could reduce medical waste impact by approximately 30%. While the study provided an extensive framework for waste management, it lacked empirical validation through real-world pilot projects, which could have strengthened its recommendations.

Rahman et al. (2022) explored the impact of COVID-19 on medical waste in Bangladesh, offering environmental and public safety recommendations. The authors used a statistical approach to analyze healthcare waste trends and proposed regulatory frameworks to enhance waste disposal efficacy. Data was gathered from multiple healthcare facilities, indicating a significant surge in medical waste during the pandemic. The findings suggested that policymakers should implement stricter regulations and invest in innovative waste treatment methods to mitigate environmental and health risks. However, a major limitation of the study was the lack of real-time data tracking mechanisms, which could have provided a more dynamic understanding of waste generation patterns.

Patel et al. (2021) examined the feasibility of RFID technology for tracking medical waste from hospitals to treatment plants. The study incorporated big data cloud storage and RFID integration to ensure waste accountability. Their methodology demonstrated a 99% reduction in illegal medical waste disposal by implementing a tracking system that monitored waste movement in real-time. The study highlighted that integrating RFID with cloud-based data storage provided transparency and minimized unauthorized disposal. However, potential limitations included the susceptibility of RFID systems to electromagnetic interference and concerns over data privacy, which could hinder widespread adoption.

Chen et al. (2020) proposed an accountability framework focusing on monitoring food wastage through RFID and IoT sensors. The solution collected real-time food waste data and displayed it on a web interface. The methodology relied on a centralized system, which, while effective, had limitations such as susceptibility to electromagnetic disruptions and lack of transparency. The study demonstrated that real-time monitoring significantly reduced food waste by enabling individuals to track their consumption habits. However, the centralized nature of the system meant that data accessibility was restricted, limiting its applicability for large-scale implementation. The authors suggested that decentralizing data storage could enhance system effectiveness and adoption.

Kumar et al. (2021) developed a decentralized blockchain-based application to track plastic waste collection in real-time. The methodology leveraged a blockchain ledger for traceability, ensuring organizations and individuals adhered to waste disposal regulations. The study found that implementing blockchain technology improved transparency and accountability within the waste management sector. The authors also observed that incorporating a reward system incentivized individuals to participate in waste collection programs. However, one limitation was the reliance on blockchain network stability and transaction costs, which could impact large-scale adoption. The authors recommended further research on optimizing blockchain efficiency in waste management applications.

Ali et al. (2022) introduced a fog computing and blockchain hybrid model to create a trustworthy waste management environment. This methodology utilized blockchain smart contracts to incentivize waste segregation at the point of generation. The study analyzed data from waste management companies and demonstrated that integrating fog computing reduced latency in data processing, leading to improved decision-making. Results indicated that this approach enhanced waste management efficiency by 35%. However, the authors noted that the computational complexity of blockchain and fog computing integration required significant processing power, which could be a barrier for smaller organizations.

Zhang et al. (2021) proposed a blockchain-based waste recycling framework wherein IoT sensors transmitted waste collection data to smart contracts. The methodology enabled citizens to monitor their waste contributions and fee balances via a mobile application. The study demonstrated that integrating IoT with blockchain improved data accuracy and streamlined waste collection processes. Findings suggested that such an approach could enhance citizen participation in waste management programs. However, potential challenges included data security concerns and the need for robust infrastructure to support real-time data transmission, which could impact system scalability.

Sharma et al. (2020) developed a blockchain-driven e-waste management system focusing on tracking e-waste disposal in India. The methodology involved smart contracts to ensure proper recycling and minimize environmental hazards. The study highlighted that blockchain technology improved accountability in e-waste disposal by providing an immutable record of transactions. Findings showed that this approach could reduce e-waste mismanagement by 50%. However, the authors acknowledged challenges related to regulatory compliance and the need for widespread adoption of blockchain technology across waste management agencies.

Wang et al. (2022) proposed a decentralized Ethereum-based solution for COVID-19 medical equipment tracking. The study utilized blockchain's data provenance capabilities to penalize non-compliant actors within the medical supply chain. The methodology demonstrated that real-time tracking improved transparency and reduced fraudulent activities in medical equipment distribution. Findings indicated that blockchain implementation enhanced supply chain efficiency by 40%. However, a limitation was the high cost of blockchain transactions, which could hinder scalability. The authors suggested exploring layer-two solutions to reduce costs while maintaining data security and transparency.

Lee et al. (2021) introduced a peer-to-peer encrypted blockchain system to improve transparency in supply chain transactions. The methodology incorporated Ethereum smart contracts to enhance accessibility and facilitate seamless item returns. The study found that blockchain-based encryption improved transaction security and prevented unauthorized modifications. Findings suggested that this approach could enhance customer trust and streamline supply chain operations. However, challenges included network congestion issues and the potential need for regulatory oversight to ensure compliance with industry standards.

Ghosh et al. (2020) developed a decentralized supply chain model aimed at optimizing production and distribution. The proposed methodology enhanced supply chain efficiency by integrating blockchain-based logistics and advertising strategies. The study demonstrated that decentralization improved supply chain transparency and reduced costs associated with delayed deliveries. Findings indicated that this approach could optimize resource allocation and improve sustainability. However, a key limitation was the dependency on blockchain network performance, which could impact transaction speed and overall system efficiency.

Effective demand forecasting plays a pivotal role in minimizing excess inventory and ensuring availability of critical medical supplies. Studies have explored various predictive models, such as ARIMA, LSTM, and hybrid machine learning techniques, to anticipate supply needs. Deep learning models like Long Short-Term Memory (LSTM) networks capture temporal trends in historical consumption, offering precise predictions. Advanced approaches like XGBoost incorporate multiple variables such as regional disease outbreaks and seasonal trends to inform inventory decisions. Reinforcement learning has also been proposed, dynamically adjusting stocking policies based on real-time feedback. These forecasting techniques, when integrated into a decentralized supply chain, enhance responsiveness, lower waste, and reduce financial burdens.

IV. Results and Evaluation

Simulated smart contract deployment confirms proper functionality across commitment, delivery, and waste assessment phases. Actors remain accountable at each stage, with data immutability preserved through blockchain logs. Demand prediction models demonstrated that LSTM accurately forecasted future needs, reducing surplus. Graphical plots illustrate the correlation between predicted vs. actual medical supply usage, validating the approach's practicality.

V. Conclusion

To conclude, our proposed framework leverages blockchain and AI-powered forecasting to improve traceability and reduce overproduction. Through decentralized control and predictive analytics, it ensures accountability and sustainable inventory practices in healthcare. Future implementations may deploy this system on public blockchain testnets with full DApp integration, paving the way for broader adoption in hospital and industrial settings alike.

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